Fractal Analyses of Sunspot Magnetic Fields

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One of the major challenges for solar physics is the understanding of the physical mechanisms which are responsible for the onset of solar flares. Observational data indicate that solar flares and sunspots are strongly linked and that the global structure of the sunspot magnetic field is a factor in the probability for flaring activity; more magnetically complex solar active regions flare more often. Through the use of data obtained with MSFC's vector magnetograph, MSFC and University of Alabama in Huntsville (UAH) solar scientists continue to study sunspot magnetic fields, the presumed source of energy for the solar flares, with fractal techniques of data analysis.

In the late 1970's Benoit Mandelbrot created the term "fractal" to describe objects which are complex on their boundaries and have self-similar subsections. Since that time, fractal-based models have commonly been used to understand natural phenomena that produce irregular structures and to describe complex, rough surfaces. Therefore, it seems reasonable to use the fractal dimension (D_f) to describe the irregularity or complexity of a solar active region and to relate variations in the magnitude of the fractal dimension to flaring activity.

In previous work, MSFC scientists teamed with scientists from UAH to study a fractal technique known as range over standard deviation experimental trend analysis (ROSETA) and identified tantalizing changes in the fractal dimension prior to a solar flare. However, the ROSETA technique is an unfamiliar tool for data analysis and its limitations in this regard have not been studied. Therefore, since ROSETA is based upon a classic fractal

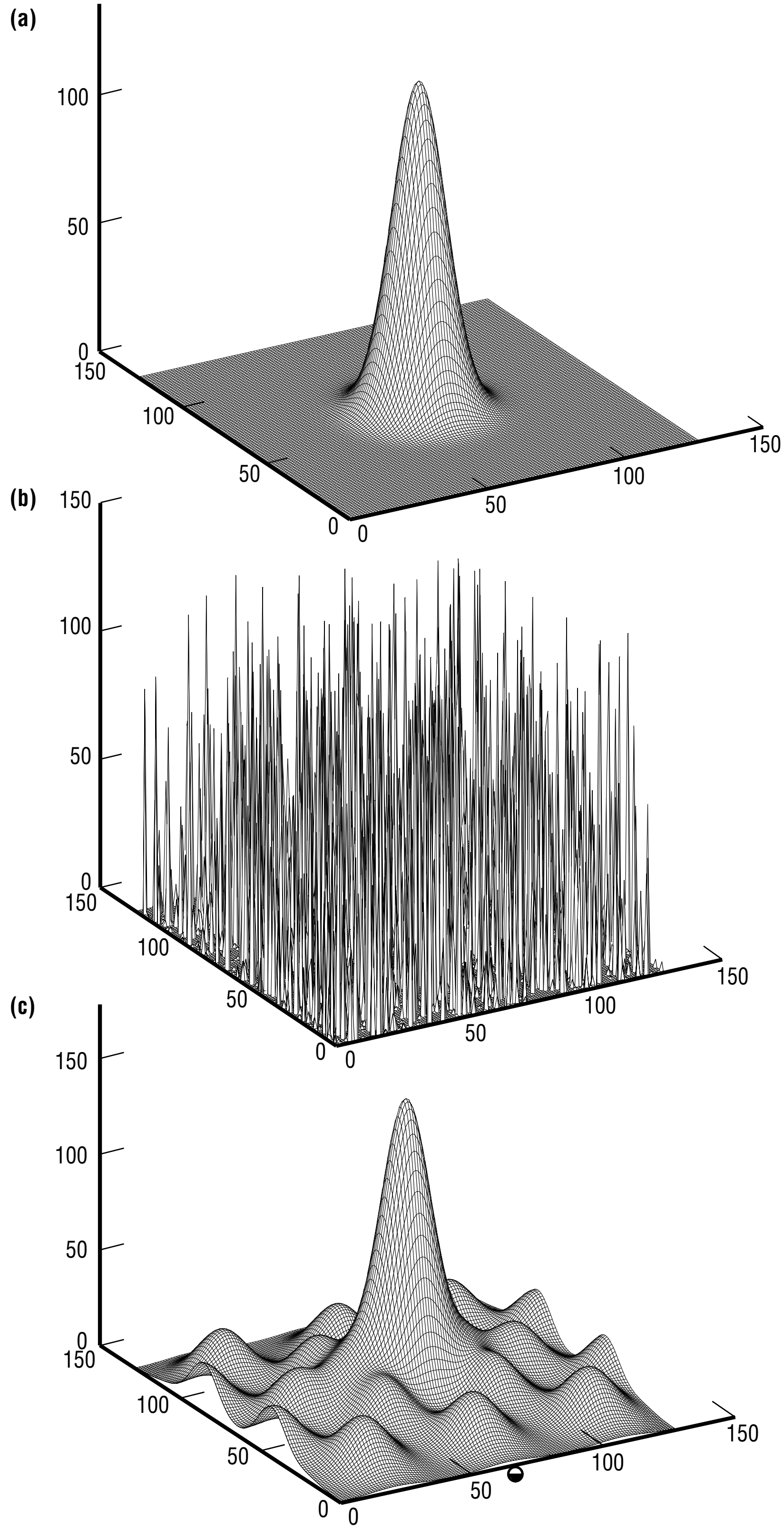

FIGURE 172.—These are examples of the test data: (a) a gaussian surface; (b) has the same array values as (a), but the positions of the data within the array are randomized; (c) a gaussian surface with offset gaussians of 20 percent amplitude of original gaussian (a).

algorithm (Hurst's rescaled range analysis), MSFC scientists have, over the last year, conducted studies to determine the efficacy of that and other fractal techniques for sunspot magnetic field research. One study concentrates on Hurst's rescaled range analysis,[1] the other[3] examines a differential box bounting (DBC) method and the Jaenisch technique.

Classical Hurst analysis involves calculating the exponent, H, from well accepted statistical parameters, the standard deviation (S) and the range (R), for various subsets of the data. Hurst exponents are related to the fractal dimension, D_f, by $D_f = 2–H$. A major drawback to the Hurst technique is the transformation of the two dimensional data set to one-dimension, since small scale changes may be masked by the conversion process. The techniques evaluated in the study of Stark et al (1996), differential box counting and Jaenisch, do not require any alteration.

All of the above techniques, Hurst, DBC, and Jaenisch, were applied to three types of data: constructed data, model sunspot data, and MSFC vector magnetograph observations. We find that the Hurst method is sensitive to differences between the constructed data sets illustrated in figures 172 (a) and172 (b). Applying the DBC method to these same data sets shows a systematic increase in the value of the fractal dimension as the complexity of the images increases (i.e., fig. 172 (a) and 172 (c)). The Jaenisch method, on the other hand, is unable to discern the difference between two visually different data sets (fig. 172 (a) and 172 (b)).

Results from fractal analysis of magnetograph data are quite interesting. A series of 10 vector magnetograms obtained throughout the day on June 10, 1991, spanned a large flare which began at 13:45 UT (the start time which is reported in MSFC data records). Hurst analysis was applied to six parameters. Although only the Hurst exponent calculated from the shear parameter[2] shows statistically significant variations over time (fig. 173), this pre- and post-flare behavior suggests that Hurst analysis should be further considered as a possible flare prediction tool.

The DBC method was tested for sensitivity to small scale changes by altering small numbers of pixels within a magnetogram image array. The DBC fractal dimension, as calculated from the unaltered data, differs from the altered data by an amount which is comparable to the effects induced by instrumental noise and is therefore not a useful tool for detecting flare related changes within the sunspot magnetic field.

Our studies indicate that the Hurst method may have some usefulness in detecting global changes over the field of view of a solar vector magnetogram. However, further work should address the most

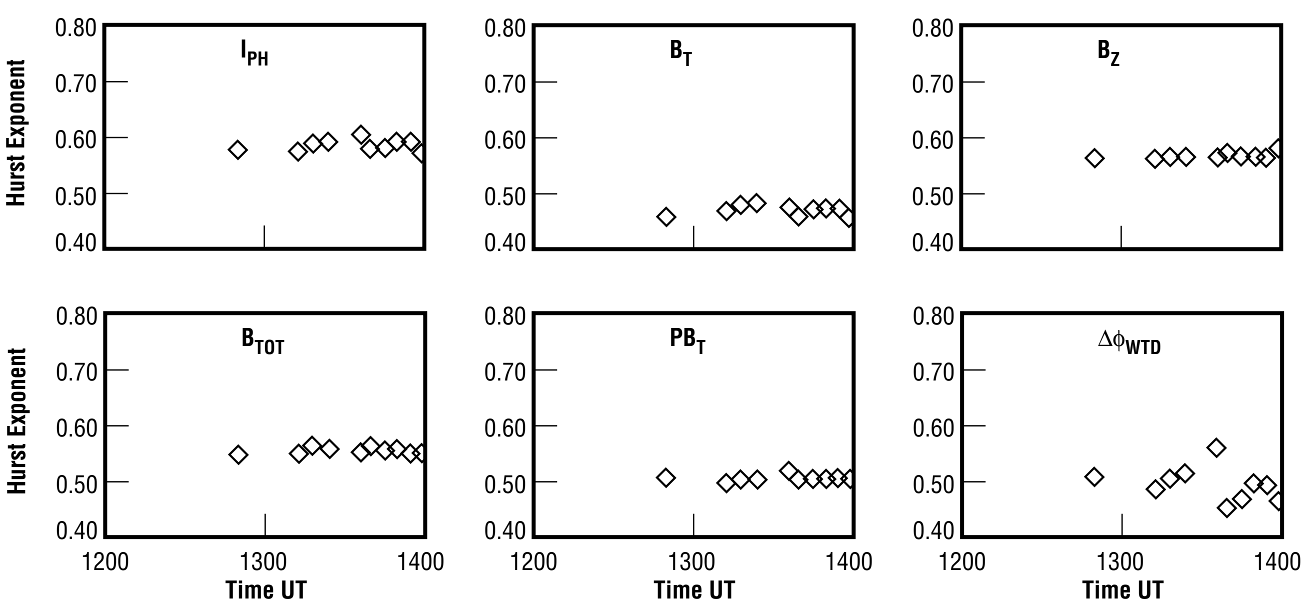

FIGURE 173.—Plots of Hurst exponents as a function of time for various parameters. Reading from left to right and top to bottom, the parameters are: photospheric (white-light) intensity (I_{ph}), the transverse component of the magnetic field (B_T), the line-of-sight component of the field (B_Z), the total field ($B_{TOT} = (B_T^2 + B_Z^2)^{1/2}$), the transverse component of the potential field (PB_T), and weighted shear angle (Df_{WTD}). Only the shear parameter Df_{WTD} shows any significant variation.

effective method of removing large-scale structures from the data and should investigate the effect of isolating magnetic areas of interest (image masking) to avoid the inclusion of random photospheric measurements in the value of the Hurst exponent. The lack of sensitivity of the DBC method to small scale changes may also benefit from a masking technique to distinguish between the sunspot and the photospheric background These issues will be addressed in the future studies.

The analysis of flare-related changes in sunspot magnetic fields can be quite challenging, since the magnetogram images on which we rely may be contaminated by instrumental effects or atmospheric seeing. Understanding the changes induced by these and other influences and deconvolving them from those caused by solar flares is a necessary step toward solar flare prediction. As we embark upon activities which place us in environments susceptible to the harmful effects of energetic particles and radiation produced by solar flares, the important role of the "solar weather person" is clear.

[1]Adams, M.; Hathaway, D.H.; Stark, B.A.; and Musielak, Z.E.: 1996, *Solar Physics*, accepted.

[2]Hagyard, M.J.; Smith, J.B., Jr.; Teuber, D.; and West, E.A.: 1984, *Solar Physics*, 91, 115.

[3]Stark, B., Adams, M., Hathaway, D.H., Hagyard, M.J.: 1996, *Solar Physics*, in press.

Sponsor: Office of Space Science

University Involvement: University of Alabama in Huntsville

Biographical Sketch: Mitzi Adams is a solar scientist for the Solar Physics Branch of the Space Sciences Laboratory. Her research involves the study of sunspot magnetic fields and the detection of changes in these fields before, during, and after a solar flare. She is currently developing techniques for studying magnetic field data using the concept of fractal dimension. Adams received a bachelor of science degree in physics from Georgia State University in Atlanta, and a master of science in physics from the University of Alabama in Huntsville.